

# Making a Case for Microsimulation as a Concept Development Tool: Case Studies of Innovative Design Concepts

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## Abstract

As congestion increases and space & resources become more constrained in the United States, transportation professionals seek new and innovative solutions through their design concepts. As such, more designs are becoming highly complex and unique to specific sites with specific constraints. This complexity introduces new challenges in evaluating the effectiveness of these designs.

A shift in the conventional design process provides opportunity to utilize the power of analysis to drive and shape these unique designs. The concept of **dynamic design** has been applied effectively to multiple design projects over the past years and allowed for the development of innovative design solutions by integrating analysis and design together into a single stage of the design process.

The idea of innovative design concepts as a way of increasing the capacity of highly constrained facilities is nothing new. What is considered as innovative is something that continues to change. In the United States, the latest in innovative intersection and interchange design incorporate diverging diamond interchanges, displaced left turns, median u turns, or other ways to reduce the number of conflicting movements at a given point.

While these concepts may not sound complicated, research is underway to find a deterministic analysis method to allow for quick and easy analyses of concepts that involve the interaction of many parts and often the interconnection and progression of multiple signals. In practice, our deterministic analysis methods currently fall short leaving a choice of having either inaccurate analyses using existing methods and software that need to be “tricked” into doing what is needed, or excessively complicated simulation-based analyses that are time and work intensive to perform. Among the examples to be discussed include the I-4 at SR 535 interchange in Lake Buena Vista, Florida. Set on the edge of Walt Disney World at one of the most congested interchanges in the State of Florida, the SR 535 interchange concept includes elements taken from echelon intersections, displaced left turns, diverging diamond interchanges, median u turns, and quadrant roads blended together in a 1.5-mile segment that could not be developed or analyzed using deterministic methods.

This paper/presentation will use case studies from projects recently completed or currently in progress to highlight a unique approach to concept development. A typical project involves traffic and engineering and roadway design working in sequence with some iterations, but typically working one at a time. This process used to develop the concepts used in the project case studies involves microsimulation and roadway design occurring concurrently and iteratively resulting in the ability to create truly innovative solutions that are often blends of multiple “innovative” concepts into one-of-a-kind solutions tailored to site-specific problems.

Keywords: innovative design, conceptual design, planning level analysis, operational analysis, diverging diamond interchange, displaced left turn, quadrant roads, roundabouts, median u-turn, microsimulation

## Introduction

Increased congestion and constrained resources are forcing a philosophical change in how transportation issues are resolved in the United States. Instead of building out or building up, transportation professionals are driven to continually evolve their design concepts to be more innovative in order to provide more for less. These designs are tailored to specific project sites and, as such, are more complex and unique. This complexity introduces new challenges in evaluating the effectiveness of these designs as they push the practical limits of existing deterministic analysis tools and design analysis methods.

This shift is a result of a need and provides an opportunity to change not only how transportation issues are resolved (from the final design perspective) but also how these solutions are created, developed, and brought through the design process. A concept of a **dynamic design** process that is flexible, responsive, and interactive has been applied to some of these highly unique transportation solutions effectively, as will be demonstrated through the case studies.

This paper will discuss the fundamentals of this concept, the process that has been applied, and benefits of this new process. In addition, specific use cases where this process may be beneficial are highlighted and one specific case study is shared to show the real-world application and results of applying this conceptual approach.

## Background

Agencies and transportation officials all over the world face similar challenges with increased congestion and more constrained environments, making it necessary to develop solutions that vary from conventional design solutions. As these solutions generally require significant investment on the construction side or are dramatic departures from commonly implemented and accepted concepts, the analysis of these solutions is critical in the decision-making process.

The changing complexity of transportation facilities and intricacies of some of the more innovative designs go beyond the analytical capabilities of existing deterministic methods and tools. As such, microsimulation is becoming more relevant earlier in the process, as it allows for the development of a model that can be calibrated to local conditions and provides the detail to capture the complex and non-traditional designs.

These new innovative designs are often a variation and/or combination of other trending designs, again increasing the complexity. Small nuances in the design may result in a significant operational impact only seen through evaluation of the system. To increase the effectiveness and efficiency of this process, design and analysis should be done together and as dynamically and interactively as feasible.

The typical workflow used in design projects does not provide for close interaction between these components which does not leverage the strength of allowing the analysis to influence the design decisions and vice versa.

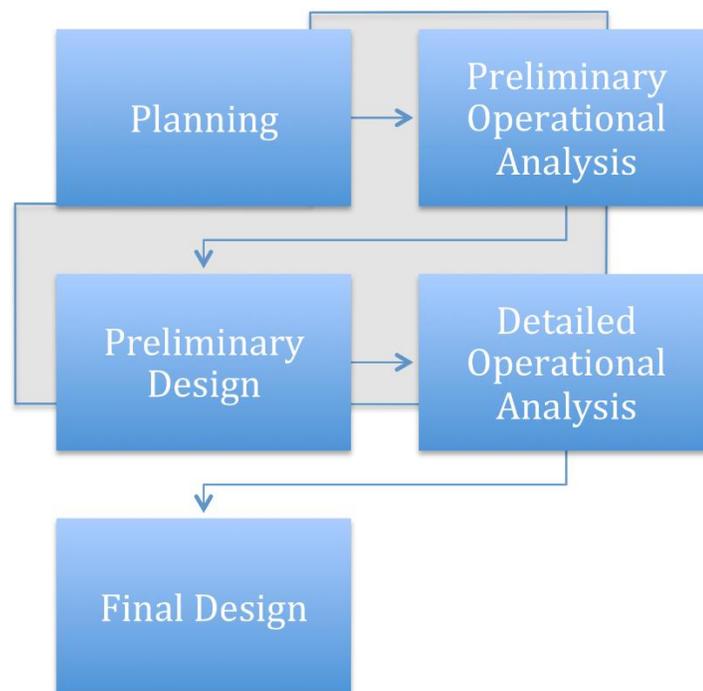
Through use cases and a specific case study, it has been shown that a modification to this conventional approach can result in true interaction between the design and analysis, resulting

in a more comprehensive design and more efficient workflow using microsimulation as the platform for both the design and analysis.

## Conventional Design Workflow

For design projects, the design and analysis components are completed separately and often by different staff, sometimes different groups within the organization, and separate expertise.

The typical project workflow conventionally used for design follows the general process shown in Figure 1.



**Figure 1 - Conventional Workflow**

More explicitly, the various components of this workflow include:

- Planning: Identify the Need
- Preliminary Operational Analysis: Capacity Analysis or other Low-Level Analysis to Identify Options (Geometry, Control etc.), often with use of Deterministic Analysis
- Preliminary Design: Sketch-level, often in Design / CAD Software
- Detailed Operational Analysis: Based on Actual Conceptual Design; May be Another Iteration of Capacity Analysis but Trend is Microsimulation
- Final Design

The workflow shown in Figure 1 provides opportunity to identify operational needs up front using deterministic analysis, develop a concept or multiple concepts that may accommodate the initial needs, and opportunity to refine the design based on more detailed analysis, with that analysis being based on the details of an actual proposed design plan.

While this conventional workflow can be successfully applied to many situations and under various traffic conditions, this workflow also has some drawbacks that inhibit its application in highly complex and unique traffic conditions, as described below.

*Deterministic analysis methods may not be robust enough to properly assess complex or congested networks.*

At this early stage of the project, it is necessary to identify network deficiencies. Traditionally, deterministic methods have been used but this is becoming less feasible and even impossible as the networks reach saturation and the complexities go beyond the limits of deterministic analysis methods. In addition, many design projects must consider the surrounding system and solutions may be on a system or at least sub-system level and deterministic models do not allow for the comprehensive evaluation of the behavior and interaction between various components.

*Separation of traffic engineering and roadway design results in inefficiencies in overall project workflow.*

Typically, the various stages of this workflow are completed in different software platforms specifically designed for each area. For example, for capacity analysis, the software is designed to be simple, intake specific information required for a deterministic analysis, and only utilize design details relevant to the analysis. When the next stage of conceptual design is started, this is done in a completely different platform (e.g., CAD software) that allows transportation designers to draw out their visions and add details of the design as necessary.

As the project moves on to the next step, assuming that the design will be evaluated using microsimulation, again, the simulation modeler will use a platform for microsimulation. This generally requires the network be built entirely from scratch rather than utilizing the information drawn in CAD.

For more conventional design applications, this approach provides an adequate amount of analysis at the relevant design stages and the “hand-offs” between stages is a one-time occurrence as the design progresses through the workflow. In the more complex designs, however, the “hand-offs” may occur multiple times and in both directions of workflow, resulting in a process that is more iterative and dynamic. Each hand-off then becomes more significant as it becomes less efficient in the overall process and loss of information and potential user error increases as the data and idea are carried between different platforms and between staff with different expertise and understanding.

*Separation of the design and analysis does not leverage the strength of each discipline.*

While both elements benefit from the outcome of the other, such discrete separation may be adding inefficiencies and limits the ability for each area to positively influence the other. A holistic solution must incorporate elements that satisfy both traffic operational needs as well as design standards. Separation of these elements does not allow for the collaboration and give and take that is needed to achieve a balanced solution that best meets the needs of a particular project. While there is feedback from the analysis back to the design (acknowledging that this may even happen over several iterations), this does not provide actual interaction and influence, which

becomes more important in the complex designs that require more rigorous operational understanding as the design evolves.

*Deterministic analysis methods may also lack the capability to analyze non-traditional designs.*

While research is underway in the United States to create deterministic analysis methods for emerging concepts such as the diverging diamond interchange and the continuous flow intersection, there will always be creativity, innovation, and necessity that will create new concepts, hybrid solutions, and other site-specific alternatives that defy deterministic analysis. Current deterministic software can often be “tricked” into providing reasonable results, but do so in isolation without the ability to account for upstream and downstream operations, and also require in depth knowledge and expertise in analysis methodology to develop, implement, and verify that the results are applicable. As such, simulation analysis has begun to replace deterministic analysis at the front end of the design process in many complex design projects.

## Dynamic Design Workflow

To address the above issues, the workflow stages can be compressed and integrated, running concurrently instead of sequentially. Rather than the stages shown above, this **dynamic design** workflow would include the following stages:

- Planning: Identification of need
- Design / Analysis: Integrated stage of concurrently developing conceptual design, analyzing, adjusting / modifying the design, re-analyzing in an iterative manner until the best design solution is achieved
- Final Operational Analysis: Fully calibrated, simulation analysis of the proposed design based on the outcome of the dynamic design and analysis stage
- Final Design

As indicated above, the stages of preliminary capacity analysis and preliminary design are combined into a single iterative stage that continues until the conceptual design is refined to the point of moving to the final operational analysis and final design. The proposed approach to this is to use a microsimulation platform to develop an initial design concept and utilize the power of simulation at that stage to identify operational issues associated with that concept. As the design resides in the simulation platform, design adjustments are done quickly and analyzed efficiently. It also allows each side to guide decisions on the other side. This is shown graphically below, in Figure 2.



**Figure 2 - Dynamic Design Workflow**

This allows for this iterative approach to be done more efficiently than using the conventional approach but also allows for a more detailed operational analysis to help shape the final design layout. Conversely, critical adjustments required by design issues can be immediately made in the analysis to help determine the most appropriate solution.

This proposed workflow follows the trend of microsimulation being used more as a preliminary analysis tool yet still utilizes the full power of microsimulation in the final operational analysis. This is done through two levels of microsimulation.

The first level that is used during the concept development is a microsimulation model that is calibrated on a qualitative level, which is always the first level of calibration used in any microsimulation project. This level of calibration involves visual calibration of the operations, calibration to vehicle flows through the model, and engineering judgment. At the conceptual level, this provides a model that has enough details to utilize for the purposes of refining the conceptual design.

At the second level, microsimulation is applied in the final operational analysis stage of this dynamic design workflow. Once the conceptual design is refined to the point of moving on to the final design stage, the model would then be calibrated at the quantitative level, using industry

standards for vehicle flows, speeds, and other calibration measures determined by the agency and the specific project needs. This then provides a complete analysis of the design to ensure that the operational outputs fulfill the needs of the overall design requirements.

Essentially, the microsimulation in this dynamic design workflow is the same microsimulation used in the conventional design workflow but applied across two stages, shifting the effort of the modeling to the front end of the project rather than completely staged at the end of the project.

With this in place, details and deficiencies can be identified that may not be possible with deterministic tools. In addition, with microsimulation, the system level evaluation is incorporated into the design process from the very beginning. For example, traditionally, the simulation analyst may identify an operational deficiency and make an adjustment to the network to mitigate that issue only to find out in the next hand-off that the mitigation proposed in the simulation is not possible from a design perspective. On the other side, the designer may see a need to adjust the curvature of an intersection approach but after investing time to modify this in the design drawings, the simulation analysis shows the negative operational impacts of that adjustment.

This approach also provides one network in a single platform. By doing so, adjusting the design automatically adjusts the network for analysis. There is no loss of information or intent between the design and analysis and vice versa. For example, a network containing an interchange and an arterial may require signalized intersection, unsignalized intersection, merging, diverging, weaving, arterial segment, and freeway segment analysis or all of the above. A majority of deterministic analysis software would save each in different files. Changes to forecast traffic would require re-inputting that data for every deterministic analysis. While the microsimulation inputs would also change, if the model is properly constructed, the changes are much simpler and in fewer places with a result of less chance for error as well.

Further, this integration of design and analysis in a single stage allows both to occur concurrently and iteratively with immediate feedback and the designer seeing quantitatively and visually any operational issues in any component of the design. In this case, the operational analysis can directly influence the design, resulting in the ability to create truly innovative solutions that are often blends of multiple “innovative” concepts that would typically be considered. The ability to respond so quickly based on information from both sides results in a truly dynamic approach to design.

## **Application of Dynamic Design**

The dynamic design workflow has been applied successfully on dozens of unique roadway and interchange design projects over the past few years. Many of these projects started with a deterministic analysis of the future no build condition. That analysis typically showed failure of one or more components of the network within the design area.

Once the network failures were identified, it was important to look at the entire system rather than each point of failure in isolation. By utilizing a network analysis, network-wide solutions could be brainstormed and developed. For example, a network failure may be mitigated by making a network adjustment upstream of the failure rather than at the exact location.

The concepts were then tested with deterministic analysis as a high level screening to narrow down network issues by providing a starting point for lane requirements and determine if an idea has any apparent fatal flaws before moving on to the next step of the process.

After this initial planning and concept development, the next stage of the process is the dynamic design and analysis stage. In this stage, roadway design and traffic simulation are commenced concurrently. While full and complete calibration of the simulation model is absolutely critical to the final operational analysis, as stated above, in this stage the model is calibrated to the first stage of qualitative calibration. At this stage, this includes observing the model closely at all locations in the network to determine if there are any model-building errors, operational deficiencies, or other issues that will affect the general outcome of the simulation analysis. This requires engineering judgment and knowledge of the study area. In some cases, some quantitative calibration may also be desired at this stage, which likely includes traffic volumes, speeds, and other measures based on the type of design project and agency requirements. As calibration is a continually increasing process with more detail of calibration added until the desired level of calibration is reached, the amount of calibration at this stage depends on the conceptual design needs and engineering judgment. The calibration at this stage is carried through to the final operational analysis stage so no calibration effort is lost or repeated, adding another point of increased efficiency to the overall design process.

Once the simulation model is prepared and calibrated to the desired or required level for the dynamic design and analysis stage, the network is adjusted for any geometric issues that are encountered in the traffic analysis and potential mitigation required for traffic operations from a design perspective are tested as soon as they are identified.

This iterative process is especially important when there are critical elements that are in close proximity such as a high volume turn just downstream from an interchange as such a situation will impact lane utilization at upstream locations resulting in capacity that is less than what may be expected or shown in a deterministic approach. Microsimulation, even during concept development, is critical as it can highlight issues that will not be caught by deterministic analysis such as lane utilization imbalances and platooning from signal to signal. The result is a site-specific analysis and design, developed quickly and efficiently, that fully addresses the corridor as a whole, as opposed to attacking each problem spot independently.

After the preferred alternative has been selected, a more refined calibration process is performed and the network is reanalyzed in greater detail for the final operational analysis prior to moving on to the final design stage.

## Dynamic Design Workflow Use Cases

The benefits of this interactive design workflow can be seen in all spectrums of design but have become apparent recently in three primary use cases:

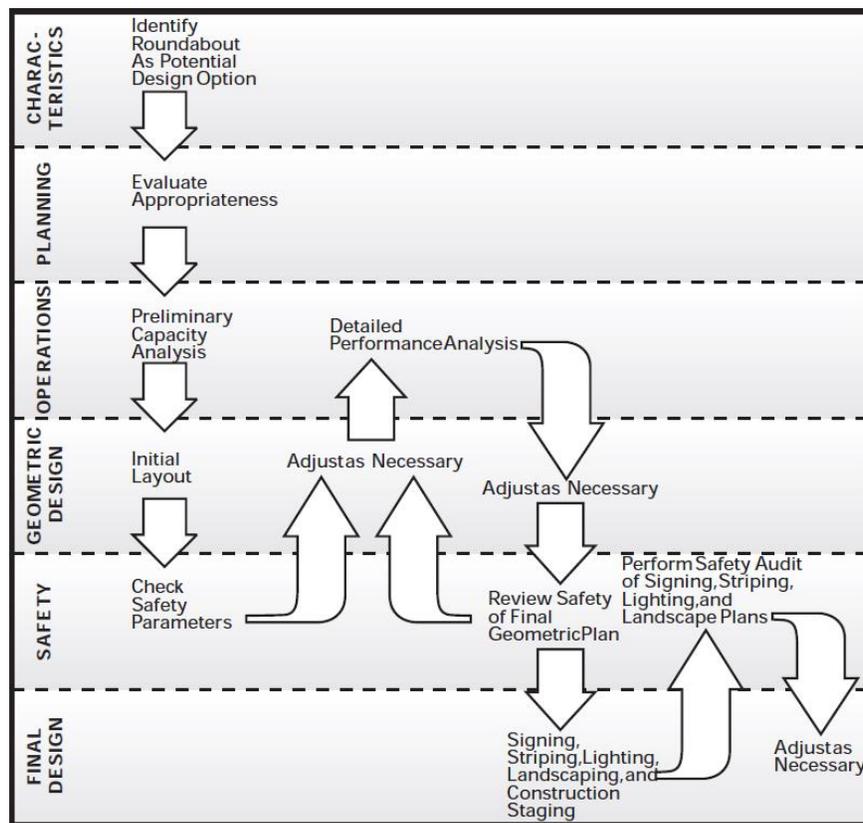
1. Roundabout Design
2. Overlapping Elements
3. Complex Intersection and Interchange Design Concepts

### Use Case: Roundabout Design

Roundabouts have evolved into a viable and sometimes preferred intersection control type in the United States over the past couple of decades. The operations of roundabouts are directly attributed to their design and, as such, the design process specifically for roundabouts has developed a slightly different approach than previously used for more conventional intersection design.

Figure 3 shows the typical workflow for a roundabout design project, as defined by FHWA in 2000. As shown in the diagram, this process already incorporates the iterative approach to design refinements and analysis. In addition, over the last decade or so, the preliminary capacity analysis has been replaced more and more by microsimulation analysis as roundabout designers recognize the value of utilizing an evaluation tool that provides more complete analysis and accounts for the details of the potential conceptual design.

While the design and analysis components remain as separate components in this approach, this workflow diagram shows the trend of trying to tie these two elements more closely together.



**Figure 3 - Roundabout Workflow (FHWA, 2000)**

### Use Case: Overlapping Elements

Closely spaced decision points created by elements in close proximity are also best analyzed in microsimulation. Even within microsimulation, proper analysis requires volumes and turning

movements inputted into the software using origin-destination pairs, not just point to point routing. Proper microsimulation would allow vehicles to make their lane usage decisions more realistically instead of one step at a time. When multiple decision points occur in close proximity, particularly when there are three or more lanes in a direction, inputting origin-destination information allows for more realistic assessments of lane utilization and potential imbalances in lane utilization at an upstream signal, for example, that cannot be identified or quantified using deterministic methods.

In many cases, the removal of what is perceived as the bottleneck of a corridor makes the presence of other nearby bottlenecks apparent. For example, fixing an interchange often reveals failing intersections nearby whose problems were hidden by the metering effect of the larger problem. Again, finding a proper, all-encompassing solution, requires an analysis methodology that can properly assess the impacts of multiple interconnected elements in close proximity.

#### Use Case: Complex Intersection and Interchange Concepts

The United States has many transportation facilities that are or have already reached their maximum capacity to accommodate current traffic conditions. Many of these facilities are in urban or suburban areas that have other environmental constraints around them – either due to built-out areas that cannot be changed or unique elements that eliminate the possibility of more standard design solutions. To address these unique situations, innovative design concepts have emerged and are gaining momentum in the United States. The Federal Highway Administration (FHWA) recently highlighted a number of these concepts as part of the Every Day Counts (EDC) program including the diverging diamond interchange, the displaced left turn intersection, the median U-turn intersection, and the restricted crossing U-turn intersection.<sup>1</sup> A previous report, the Alternative Intersections and Interchanges Informational Report (FHWA, 2010), also included quadrant roadways.

Together, these concepts seek to improve operations at intersections and interchanges not by adding lanes, but by optimizing signal operations through removing phases from the traffic signal. Reducing the number of phases in the traffic signal can be accomplished by removing movements at the main intersection by prohibiting turns and diverting allowable travel paths (see Figure 4 for a median U-turn example and Figure 5 for a left turn at a quadrant road) or by diverting physical travel paths (see Figure 6 for a displaced left turn at a continuous flow intersection and Figure 7 for a left turn at a diverging diamond interchange).

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<sup>1</sup> [http://safety.fhwa.dot.gov/intersection/alter\\_design/](http://safety.fhwa.dot.gov/intersection/alter_design/)



**Figure 4 - Left turn movement at a median U-turn**

While these concepts reduce the number of signal phases, they also increase the number of signals making the interaction between the elements within the concept critical to determining the feasibility of the improvement.



**Figure 5 - Left Turn at a Quadrant Road**



**Figure 6 - Displaced Left Turn at a Continuous Flow Intersection**



**Figure 7 - Left Turn at a Diverging Diamond Interchange**

With these emerging concepts, analysis becomes more difficult. Research is underway to find deterministic analysis methods that would allow for quick and easy evaluation of concepts that involve the interaction of many parts and often complex traffic control such as interconnection and progression of multiple signal controllers. While deterministic methods may provide some level of evaluation of these types of designs, the methods may fall short in capturing the true interaction between elements of the system proposed and may not account for all of the

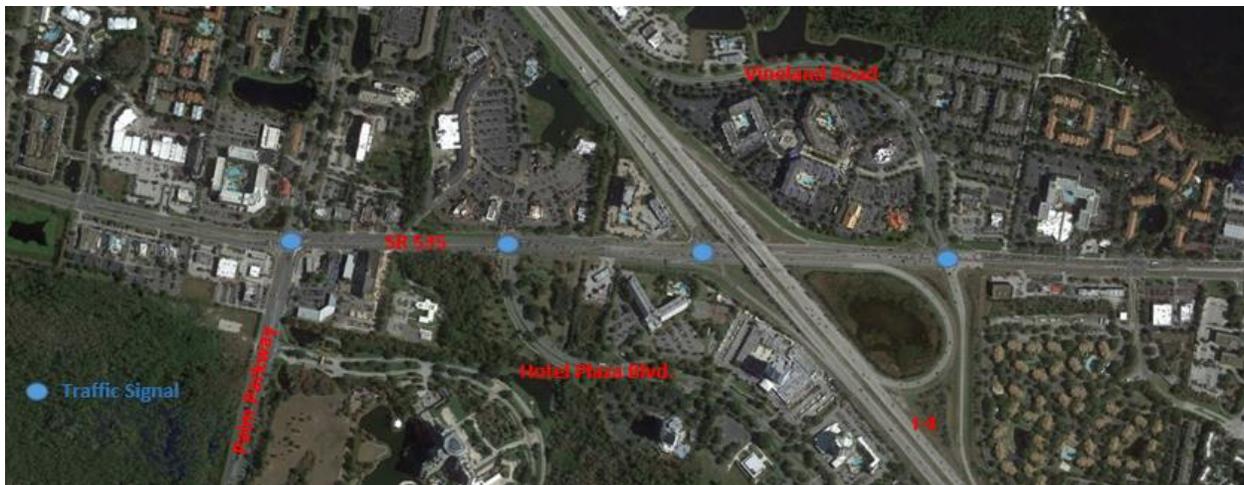
intricacies of the design itself. In these cases, microsimulation is used more and more to evaluate the full system, allowing for incorporation of specific design details and true interaction between all components of the system.

### Case Study: I-4 at SR 535

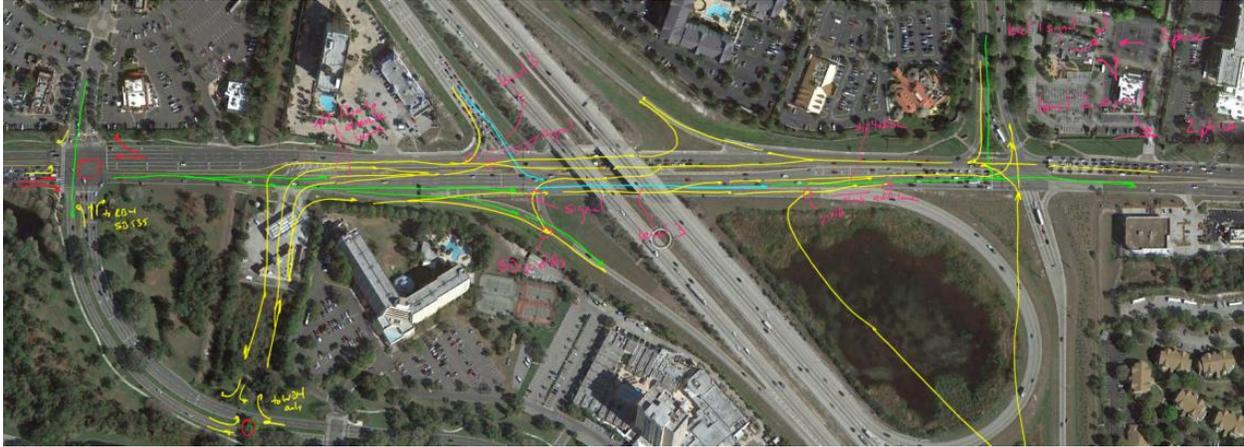
The following case study is part of an ongoing project along Interstate 4 through central Florida that includes 80 miles of freeway that travels through downtown Orlando and passes by such tourist attractions such as Universal Studios Florida, Sea World, and Walt Disney World. The SR 535 interchange is adjacent to Walt Disney World and carries a mix of commuter and tourist traffic. Figure 8 shows the locations of the existing traffic signals within the improvement area. Existing congestion from each of these existing signals significantly impacts upstream signals in each direction. Current congestion spills back on to Interstate 4 causing significant impacts upstream on the freeway that can stretch for miles.

While the project started with improvements at the interchange, the project limits were extended along SR 535 in each direction away from Interstate 4 to fix any operational problems on the corridor that could impact freeway operations.

Deterministic analysis at each of the existing signals was performed to identify the movements causing problems at each location. Each intersection could not be made to operate at acceptable levels of service through simple improvements at the intersections such as adding through or turn lanes. Ideas were instead developed to alleviate problematic movements by grouping conflicting movements, often by relocating them. The conflicts at each existing signal location were adjusted to remove phases from the signals. The resulting signals were checked using deterministic analysis. Lane configurations resulting from this analysis were used to establish the starting point for the rest of the conceptual development process. Figure 9 shows the level of detail available at the start of this process.



**Figure 8 - Existing Signals Along SR 535 Corridor**



**Figure 9 - Initial Concept Development Sketch**

Once the concept development was initiated, operational issues that were not apparent during the initial deterministic analysis were found. The project limits were extended to the north to incorporate Palm Parkway. Geometric design discovered vertical profile issues that indicated grade separated movements envisioned in the initial concept were fatally flawed. Coordination with local stakeholders introduced further changes, all of which were incorporated into the roadway design and traffic analysis simultaneously.

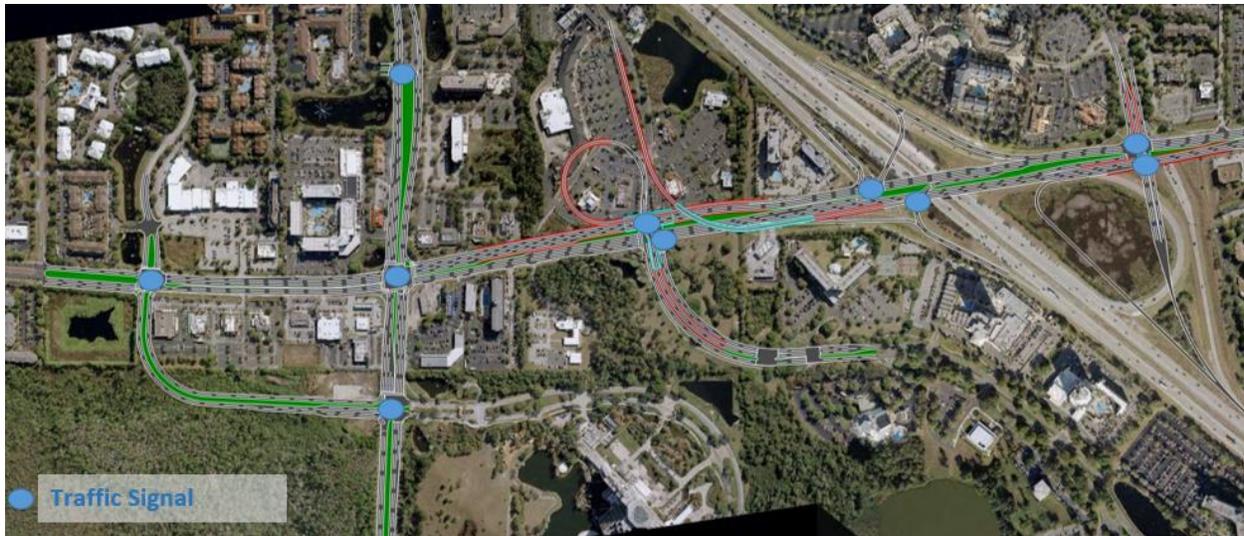
The intersection at Palm Parkway had one signal and was changed into a concept that included four signals, two generated by a quadrant road in the northwest quadrant of the intersection and another by a median U-turn on the east leg of the intersection, as shown in Figure 10. Due to the proximity of the problem intersection of the Hotel Plaza Blvd. intersection to the south, Palm Parkway improvements could not extend to the south and queue lengths to the south had to be minimized to the extent possible.



**Figure 10 - Proposed Improvements at Palm Parkway**

The remaining improvements along the corridor included a partial DDI, displaced left turns, and two echelon intersections. As shown in Figure 11, the resulting proposed improvement increased the number of signals on the corridor from four (see Figure 8) to ten. The ten proposed signals, however, are all two-phase signals. Each individual signal operated well in deterministic analysis (which was used as a starting point for signal timing). Microsimulation, however, increased the number of lanes indicated in the deterministic analysis, based on the interaction between the signals caused by queueing and imbalances in lane utilization between the successive decision points along the corridor. Diverge points downstream of signals required the addition of through lanes as look back distances (the distance upstream of a decision point at which lane changes are made by vehicles in advance of making a turn or an exit ramps) created lane utilization imbalances at upstream signals.

The resulting corridor improvement at the SR 535 interchange could not have been developed in the short month-long timeframe using a traditional approach where analysis and design are handled sequentially as opposed to the *dynamic design* approach used as part of this project.



**Figure 11 - Signal Locations in Proposed Improvement**

## Conclusions

The conventional workflow of a project separates design and analysis components. Using **dynamic design** encourages design and analysis to be concurrent activities, which can foster efficiency and positive feedback that allows each discipline to influence the other resulting in solutions that balance tradeoffs between design and analysis to yield better overall solutions.

The use of the dynamic design process is especially beneficial for roundabout design, designs with closely spaced elements or where adjacent elements may impact the study area, and with complex intersection or interchange concepts. In these use cases, existing deterministic analysis methods do not allow for the evaluation of the designs at a system or network level but rather as isolated components of a network. As such, these types of design projects have shown to benefit from a more iterative approach, as proposed through the dynamic design workflow. Deterministic analysis methods are not capable of looking at designs as part of a cohesive whole and may not be accurate enough even to establish lane configurations.

The dynamic design approach allows project teams to collaborate more closely and may foster innovation and efficiency to come up with more innovative solutions to complex problems and to better deal with the unique issues associated with innovative and, often, one-of-a-kind designs which can result when design and analysis complement each other. The effort to develop the simulation model, as proposed, is shifted from the later stages of the design process rather than added to the process, resulting in no additional effort in the overall process. This shift to the earlier stages of the design process allow the power of a simulation to be used not only as a check of the design but as a driver for design decisions.

The proposed approach of **dynamic design** allows the entire process to leverage the strengths of this integration, resulting in an overall better design option and improved decision-making.

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